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A theory for treating visual vertigo due to optical flow

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Running Title: Treating Visual Vertigo Due To Optical Flow

ABSTRACT

Virtual reality (VR) training[1] that provides optic flow stimuli and visuo-vestibular conflict[2] has been suggested as a way to treat dizziness patients with visual vertigo (visual dependence). We propose a simple framework based on a hypothesis that the degree of dizziness depends on the offsetting between the destabilizing effect of optical flow and the stabilizing effect provided by stationary objects in the visual field. We define a total destabilizing potential (TDP) which is the ratio of the destabilizing effect over the stabilizing effect. The approach is to gradually increase the patient's tolerance of a higher TDP through exercises that may be described as an inverse of the traditional gaze stabilization exercises for vestibular rehabilitation. The theory proposes that an important ingredient in VR training is to incorporate a stationary anchor to help synchronizing the visual sensory to vestibular and somatosensory inputs. The scheme can also be adopted economically with computer generated imagery or used by patient in certain every day environments.

1. Introduction

Our hypothesis is derived from a patient's case history. The patient, the first author (CPC), was then a 59-year old male professor who experienced an attack of benign paroxysmal positional vertigo (BPPV) in October 2004. The BPPV was cured through one session of Canalith Repositioning Procedure, but visually induced space-motion discomfort continued for 18 months almost without break. The dizziness affected his daily life significantly. He was unable to lecture in front of class, or to view slide presentations from close distance. He also had troubles attending meetings, scrolling on computer screens, driving, and inside grocery stores, buffet restaurants, airport terminals,

or rooms with colorful or complex decorations. Dizziness often struck when he lowered his head to sign credit cards or looked at a keyboard; feeling his eyeballs locked to the looking-down position and needing to struggle to lift his head back to the normal level.

Starting March 2005 he kept a daily log of a subjective dizziness index. The highest and lowest day time values and a usually minimum night value, as well as notes on environments that might affect the dizziness, were recorded. A consistent experience that eventually emerged suggests that, when the visual environment was surrounded by large stationary structures such as close-by tall buildings, the discomfort tended to be less than areas surrounded by lower buildings. This difference became larger when the scene became busier due to the presence of people or objects (Fig. 1). After the patient participated in a VR experiment directed by Dr. Emily Keshner at the Rehabilitation Institute of Chicago in December 2005, he attempted a stimulation exercise entailing trying to watch as long as possible fast moving trains from the rear seat inside a parked car. He tried to use the sight of the car's stationary front window frame to resist the disturbing sight of the moving train. He also practiced the train viewing exercise at subway stations in which the stationary platforms provided the anchoring effect that countered the visual perturbation from the moving train. The dizziness frequency and intensity both subsided by late January 2006, and practically gone in late March (Fig. 2).

2. Hypothesis

The history of this case suggested that the dizziness due to optical flow may be inversely correlated with the presence of stationary noncomplex images in the field of view. If we define a destabilizing potential (*DP*):

$DP = D/S$,

where *D* is the destabilizing effect and *S* is the stabilizing effect, then a larger *DP* will be

associated with more frequent or intense dizziness. The next task is to define *D* and *S*.

Figure 3a is a schematic diagram depicting an *aiming* area *A* embedded in a *background*

environmental area *B*, like a picture-in-picture TV. We propose that *D* and *S* are functions

of both relative visual area of A and B and their velocities. If the aiming area contains

optical flow such as that produced by a long moving train, an approximation is to let *D* =

A × *f(V)* and *S = B* where *V* is the velocity of the optical flow. In general *V* is a three

dimensional velocity field that may also vary with time, but for the simplest case of linear

constant velocity, *f(V)* will be represented by a constant speed,

$$DP = D/S = A/B \times V.$$

One may further consider, based on empirical and heuristic logics, that the total effect on

a visual vertigo patient is *DP* integrated over the duration of exposure,

$$TDP = \int D/S \, dt = t \times A/B \times V \text{ for constant } A, B \text{ and } V.$$

It is obvious that a patient will not suffer visual vertigo if either *t* or *A* or $V \rightarrow 0$.

  To develop a therapy, the patient will be subject to a lower value of *TDP* initially,

which may be determined subjectively by the tolerance of the patient or by equipment

such as dynamic posturography. The *TDP* can then be increased with the progress of the

therapy by increasing either *t*, *A/B*, or *V*. For the train viewing case, the patient can only

control t. In a laboratory or clinic environment, *A/B* and *V* can all be controlled. One

example is to expand *A* in Fig 3a as the therapy progresses.

  This proposed scheme is very different from the gaze stabilization scheme used in

the traditional therapy for vestibular rehabilitation[3]. In the latter, the aiming area *A* is a

small single object with slow relative motion such that the eyes can be trained to stay

focused on the object, while the background environment is typically busy with fast

optical flow or complex patterns (Fig. 3b). The patient is being trained to stay with *A*

while ignoring *B*. In the proposed scheme, *A* is the fast moving optical flow and *B* is the

stationary and noncomplex background. The patient not only does not ignore *B*, he or she

uses *B* as an anchor to overcome the destabilizing effect from the gazing at *A*.

3. Remarks

The proposed theoretical framework is based on one case only but its approach

resembles previous studies of optokinetic training[4] in which patients are exposed to

repeated optokinetic stimulation. Our hypothesis differs in that we formally consider both

background and foreground, as well as their relative velocities. It can also be compared

with the gradual increase of height in VR treatment of acrophobia patients[5,6]. These

patients experience difficulty as the increased distance from ground causes them to lose

reference in space, which is equivalent to a large A/B ratio for the visual vertigo patients.

The gradual increase of height is equivalent to a graduate increase of the area *A* in Fig. 3a.

The difficulty of measuring visual-dependence dizziness has been a significant

problem in diagnosing, monitoring and treating visual vertigo. The destabilizing potential

DP or *TDP* proposed here can be used as a parameter to gauge consistently the degree of

dizziness. For example, a VR image of Fig. 3a may be incorporated in a posturography

system with varying *A/B* ratio or *V* velocity to assess the dizziness quantitatively. This

can facilitate monitoring the progress and the effectiveness of treatments.

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Figure 1: Schematic figure to show the contrasts of two background scenarios with the same optical perturbation. The Destabilizing Potential as introduced later in the text is large for the left panel and small for the right panel.
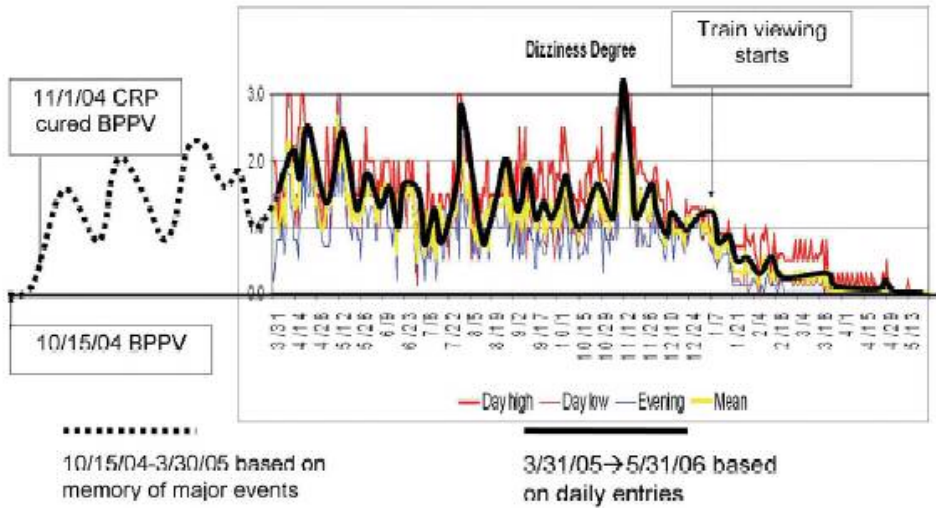
Figure 2. Daily dizziness index of the patient, <1.0 indicates mild dizziness, 3.0 indicates severe dizziness including oscillopsia. Thick lines are smoother versions of daily mean.
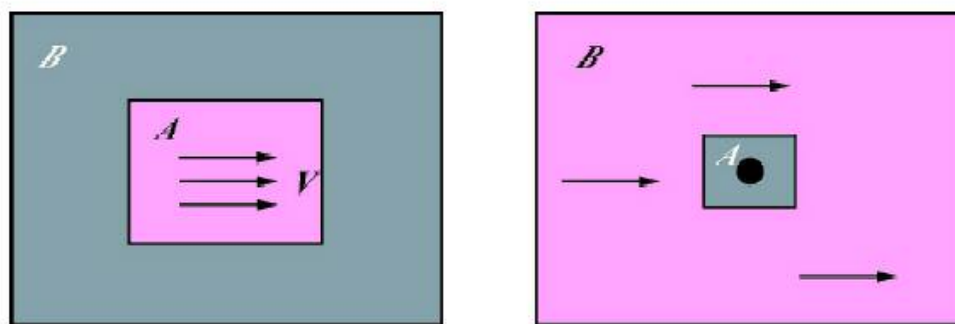
Figure 3. (a) Parameters determining the destabilizing potential. Colored area indicates visual perturbation. (b) Gaze Stabilization for vestibular rehabilitation. Colored area indicates visual perturbation.